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Effect of Packet Inter-arrival Time on the Energy Consumption of Beacon Enabled MAC Protocol for Body Area Networks

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Abstract

One of the major concerns for the development of Wireless Body Area Network (WBAN) is to increase the network lifetime. IEEE 802.15.4 standard for Medium Access Control (MAC) layer can be used for energy efficient and reliable transmission by modifying the different control parameters. Such a modification is very difficult, because an accurate model for the influence of these control parameters of minimum energy and delay is not available. Moreover, there is no mechanism available how to adopt and implement these parameters that can implement on the Body Nodes (BNs). In this paper, we provide the mechanism for emergency data along with normal and periodic data by modifying the superframe structure. Coordinator transmits and extra beacon upon the request of emergency data. A comprehensive analysis of energy consumption of BNs including the affect of packet inter-arrival time is given in this paper. Analysis show that, Contention Access Period (CAP) of superframe is not feasible for emergency data due to its extra delay and energy.

Keywords: IEEE 802.15.4; CSMA/CA; TDMA; Inter-arrival Time; RFID; Wakeup Radio

1. Introduction

A special purpose Wireless Sensor Network (WSN) that is used for health monitoring is known as Wireless Body Area Network (WBAN). Invention of small, low cost, and wearable devices have attracted the interest of different researchers. As many people suffer from different kinds of diseases, therefore they need a continuous monitoring system. For this purpose, WBAN is helpful without any restriction and need of hospitalization. This process is further used to increase the personal health care systems[1]. WBAN consists of BNs that are used for both medical and non-

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medical purposes. For medical applications, these devices are placed or implanted inside the human body to measure and transfer the real time data or audio signals. For non-medical applications, these devices are used for measuring the environmental conditions, industrial environments, motion detection of the animals in the forest, security, etc. All these applications use different power consumptions according to their data rates. Data rates and power consumptions of implanted devices are very low as compared to that of wearable devices. A list of devices with energy consumption and data rates are given in the table. 1.

WBANs consist of different BNs are attached or implanted inside the body of the patient. BNs collect the patient's information and transmit it to the main server. Different researchers use different network topologies. However, star topology is more appropriate, having a transmission range of 3-6 meters with different data rates[2,3]. WBAN is a small and scalable network to support different new devices. Nodes do not transmit data all the time. BNs can be in sleep or low power listening mode to save energy.

For efficient and long term health monitoring systems, an effective and low power technique is required. IEEE 802.15.4 standard for MAC layer is used to reduce the energy consumption for communications. Traditional MAC protocols consider the bandwidth utilization, throughput enhancement and reducing the transmission delay. The main sources of energy consumption in MAC protocols are; idle listening, packet retransmission retries, Clear Channel Access (CCA), packet inter-arrival time and collision. MAC layer plays a significant role to overcome these issues which ultimately increase the network lifetime. IEEE 802.15.4 standard for MAC layer has two periods: Contention Access Period (CAP) and Contention Free Period (CFP) and an optional Inactive Period (IP). In CAP, nodes contend to access the channel for transmission. Each node has equal probability to access the channel. However, CAP mechanism is inefficient for emergency data due to more control overhead and energy consumption during packet retransmission and CCA. Moreover, this mode does not provide the guaranteed data due to high path loss of the human body (Inside/Outside). While in CFP period, Coordinator allocates the Time Division Multiple Access (TDMA) based guaranteed time slots to the nodes requiring specific bandwidth. Each node transmits its data during its own time slot. Again, this mode does not solve the emergency data transmission like; blood pressure and heart beat during critical situations. Another problem related to TDMA based mode is that when a node has a time slot of fixed length and the sensed data requires more time for transmission. In this situation, node consumes more energy during synchronization process. All nodes in CFP period, receive periodic control packets to update their clock which ultimately consumes extra energy.

So, the prime requirements while designing WBAN are: low power consumption, minimum transmission delay, reliability, maximum throughput, and high security. To tackle these energy issues and handling emergency data, we propose an efficient IEEE 802.15.4 based MAC protocol. We divide our mechanism into three phases: normal, emergency, and periodic. During first phase, nodes transmit using slotted CSMA/CA mechanism. For periodic data, coordinator assigns the TDMA based time slots for fixed bandwidth. In case of emergency data, AP transmits an emergency beacon message to handle this situation. We also incorporate the packet inter-arrival time to analyze the energy consumption. Figure. 1. shows the data transmission mechanism in WBANs.

The rest of the paper is organized into following sections. Sections 2 and 3 give the related work and motivation. Detailed description of our protocol is given the section. 4. While, section. 5. gives the analysis and simulation results of our proposed scheme. Conclusion and future work is given at the end of the paper.

Table 1: Some Body Nodes and Parameters[7].

Device Type	Parameters	Energy Consumption	Data Rate
On Body Device	EEG	Low	Low
	ECG	Low	Low
	Heart Rate	Low	Low
	Blood Pressure	Low	Low
	Games	High	High
	Mp3 Player	High	Medium
In Body (Implanted)	Glucose	Low	Low
	Brain Liquid Pressure	Low	Low
	Drug Delivery Capsule	Low	Low
	Deep Brain Stimulator	Low	Low

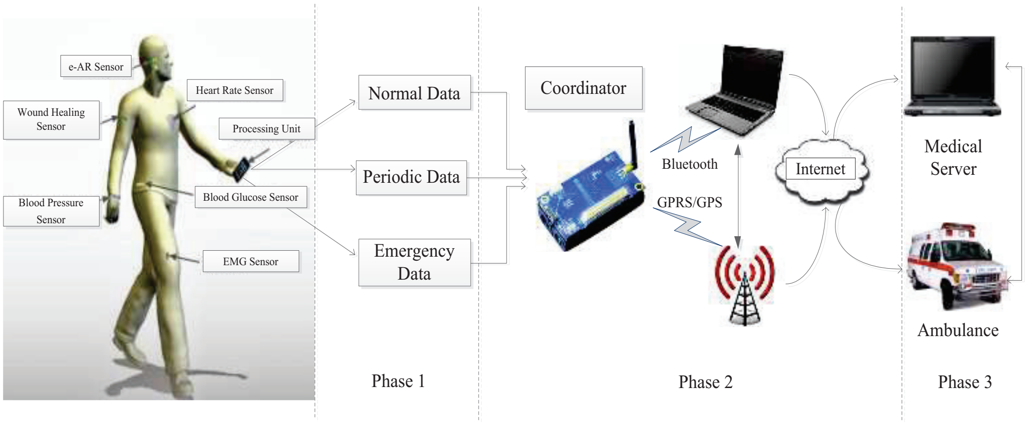


Fig. 1: WBAN data transmission phases .

2. Related Work

Extensive research has been conducted for the development of an energy efficient and reliable MAC protocols for WBANs. Different researchers used the IEEE 802.15.4 and IEEE 802.15.1 standards for Personal Area Networks (PANs)[4]. The IEEE 802.15.4 MAC standard is designed for PANs. The main reason for its attraction is its low duty cycle, low data rate, and low energy consumption. In the last few years, IEEE 802.15.4 standard has been used for WBANs. Another main reason for its use is the superframe structure to increase the Quality of Service (QoS) requirements for WBANs. One of the major drawbacks of the IEEE 802.15.4 is periodic listening to the beacon messages which, is the major source of energy consumption in BANs.

CSMA/CA mechanism of IEEE 802.15.4 (slotted and unslotted) is inefficient due to collisions of packet and large energy consumption during channel sensing and CCA. Protocols based on TDMA are also being used by many researches. However, TDMA mechanism is not suitable for emergency data transmission because of the fixed time slot allocation in the beacon message. To tackle these issues, authors in[5], propose an efficient RFID-enabled MAC protocol for WBANs. They use separate control channel along with main data channel to reduce the energy consumption. Nodes transmit normal data according to pre-scheduled mechanism, while the emergency events are handled by using RFID method. When a node has an emergency data, it transmits control signal via control channel to the coordinator. Coordinator then transmits emergency beacon to that node for channel contention. If the channel is found busy, node waits for beacon interval and it will contend again after this time. Nodes sleep when they have no data to save energy. To reduce the energy consumption of the nodes in WBANs, we need to adjust the duty cycling mechanism for efficient energy utilization. Nodes having low duty cycles do not receive the frequent synchronizing and control information. In[6], authors investigate and handle the normal, emergency, and on demand traffic by using the traffic information of the nodes. This traffic information is saved in the traffic wake up table and coordinator maintains this table according to the data pattern. They adjust the duty cycles of the nodes according to their data patterns to save energy. A wake up radio is also used to send the control signals to the coordinator during emergency data. Nodes transmit normal routine data to the coordinator based on the normal wake up method. While, the emergency data is generated by any node. A wake up radio mechanism for emergency and on demand data is used. If more than one node has the same data pattern in the wake up table, then the medium is allocated to the highest priority node.

For WBANs, we need a suitable protocol with low duty cycle, low energy consumption, and low delay. Periodic listening, idle listening, extra control overhead, and collision are the main reasons for energy consumption. To overcome these issues, authors in[7,8], give the analysis of the out of band wake up radio. The wake up radio chip is cheap and placed in the normal circuit of the node. Channel access and data transmission mechanism are predefined. Nodes switch into sleep mode when there is no data for transmission. When a node has data, wake up radio transmits the control signal to the main circuit for wake up and data transmission. Otherwise, the node remains in the sleep mode to save energy.

In[9], authors provide an energy consumption analysis of slotted CSMA/CA algorithm of IEEE 802.15.4 standard. Nodes consume more energy while using CSMA/CA mechanism due to channel sensing, backoff periods during busy channel, packet retransmissions, and CCA. This mechanism increases the reliability of data. However, message retransmissions and CCA procedure consume more energy and introduce extra delay which is not feasible for WBANs. Moreover, authors do not provide any mechanism for emergency events. A survey of different MAC protocols and IEEE 802.15.4 for WBANs is presented in[10,11]. Authors evaluate and present the performance with an analytical model for different performance parameters: delay, throughput, collision, low power listening and energy minimization. They also give the path loss analysis for in body, on body and off body communication.

3. Motivation

Due to limited energy of BNs, an efficient handling of resources for smooth and error free operation is needed for WBANs. However, energy efficiency and delay are the main tasks during the design of WBSNs. For more reliability, these protocols should tackle the following issues:

- Minimum delay during emergency data
- Reduce the idle period
- Decrease the energy consumption during retransmission and CCA
- Increase the sleep time during no data
- Reduce the control overheads

We propose a MAC protocol based on IEEE 802.15.4 standard to address these issues for maximum lifetime and emergency data. The details of our proposed protocol are given in the section. 4.

4. Network Model and Protocol Description

In the proposed protocol, we place different BNs on human body. These BNs are of two types: Fully Functional Device (FFD) and Reduced Function Device (RFD). FFD can be simple node or coordinator, which transmits data to the external device. While, RFD works only as a simple node. BNs collect sensed data and transmit to the local processing device, which transmits it to the main coordinator. These nodes have limited battery power so, we need to reduce the computation overhead. During network operation, uplink traffic is more than down-link traffic as BNs transmit data more frequently.

4.1. Data Types

We use three types of data; Normal Data (ND), Periodic Data (PD), and Emergency Data (ED). BNs transmit ND like body temperature, or any type of psychological data which does not require any particular reliability or delay. Node transmits this type of data by using CSMA/CA mechanism. BN first senses the medium for channel access. If the medium is found idle, it will perform an optional CCA which adds more reliability. However, if medium is found busy, nodes wait for a random amount of time according to IEEE 802.15.4 standard. After this time, node senses the medium again and transmits the data after successful channel access process. PD corresponds to such type of data that a doctor needs after some regular intervals of time like audio or video data. This data does not have any type of delay constraint. Nodes transmit data during CFP of superframe. AP assigns the TDMA based time slots to the nodes having periodic data. Both the CSMA/CA and TDMA mechanisms have some drawbacks. They do not provide any type of emergency data handling mechanism. As the emergency data like Electric Cardio-gram (ECG) has highest priority, therefore we need a mechanism with minimum delay. We differentiate these types of data on the bases of their

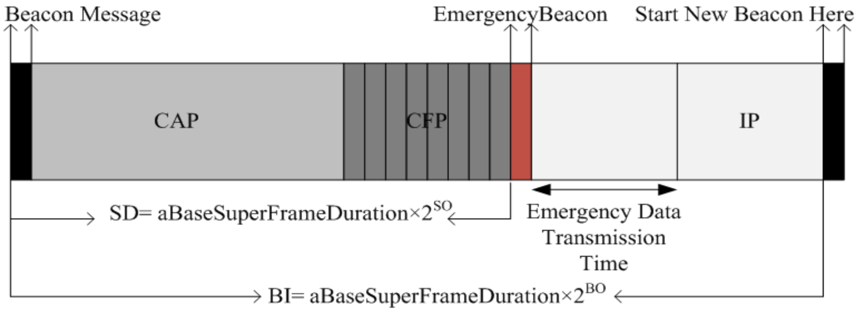


Fig. 2: Superframe structure.

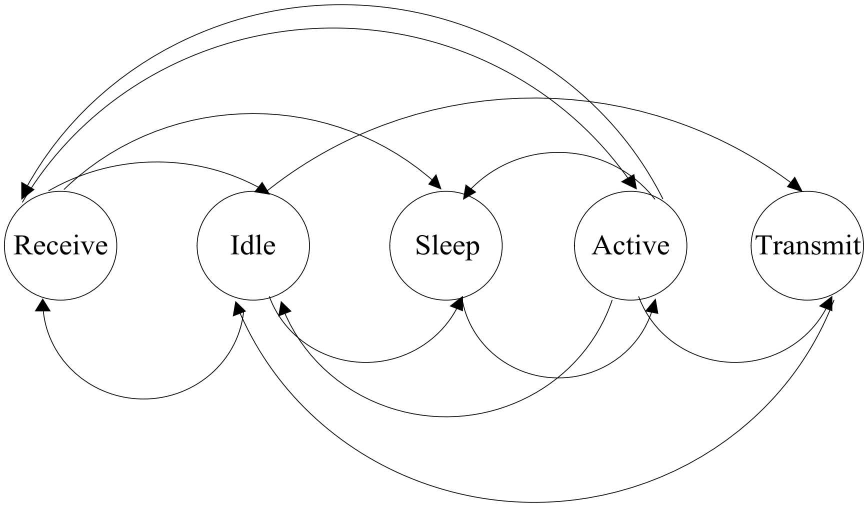


Fig. 3: Network flow diagram.

data rates and packet sizes. ND, PD, and ED are assigned normal priority $Data_{normal}$, $Data_{periodic}$, and $Data_{emergency}$ respectively. Based on these priorities, nodes and AP take decision during resource allocation and transmission. BNs calculate the priority of each data on the bases of the following equation;

$$Priority = \frac{DataType}{\lambda t \times P_{size}} \quad (1)$$

Where, λt is traffic generation rate and P_{size} is the length of data packet generated by the BN. Emergency data packets with high traffic generation rates have the highest priority and need to be send on priority basis. Time critical data must be delivered quickly without any delay. In case of extra delay, buffer will overflow and packet will be lost.

4.2. Superframe Structure and Backoff Periods

Superframe structure of IEEE 802.15.4 for WBAN consists of four periods: CAP, CFP, IP, and EX period. Superframe structure starts with beacon packet which contains all the information about time slots, coordinator, BNs, and start and end of this period. In CAP, all nodes contend to access the channel for ND transmission while in CFP, nodes requiring fixed bandwidth and having PD transmit their data. During emergency, BN generates a request for AP to transmit the data immediately without any delay. AP then transmits a special beacon message for that node based on the data type. This emergency data handling mechanism uses the IP. This is because if we use CAP for this transmission, normal data transmission can be interrupted or emergency data has to wait during busy channel. If a

node does not have any data, it will switch into sleep or idle listening mode according to the situation.
If the channel is busy, nodes perform random backoff process in CAP. The random backoff period is based on the amount of data. A small backoff period will be assigned to the node which has less amount of data. Nodes having more data wait for more time to avoid collisions. However it adds extra delay. Figure 2 and 3 show the superframe structure and network flow diagram. Nodes switch from one state to other state according to data and task. During idle state, node can switch into sleep, idle, or transmit state. Similarly, each node changes its state accordingly.

5. Simulation Results and Performance Evaluation

This section gives the energy consumption analysis of the proposed protocol. We use WiseNET transceiver[12] for simulation purpose. All parameters are listed in the table. 2. After the initialization of the network, AP transmits the beacon message containing all the information of the superframe duration, BNs, and GTS time slots. During CAP, nodes contend to access the medium having same probability. If the channel is found idle, node performs CCA to avoid the collision. After first CCA, if channel is found idle, node transmits the data and waits for ACK message. Sender node receives the ACK during its predefined time which is equal to Propagation Time ($2T_p$). If the node does not receive the ACK during this time, it will assume that the packet is dropped. In this situation, node will attempt to retransmit the packet. ACK message is optional for authentication. Effects of ACK message and busy channel on the energy consumption are shown in the figure. 4. Whereas, energy consumption during transmission, reception, ACK, and control packets is calculated as;

$$E_{total} = E_{normal} + E_{bwait} + E_{rec} + E_{tran}. \tag{2}$$

$$E_{normal} = P_i(\lambda p - (T_{setup} + T_{beacon} + T_{cca} + T_{data} + T_{ACK} + T_b\tau). \tag{3}$$

$$E_{bwait} = P_{rec} \times T_b\tau. \tag{4}$$

$$E_{rec} = P_{rec} \times T_{setup} + 2T_c + 2T_p. \tag{5}$$

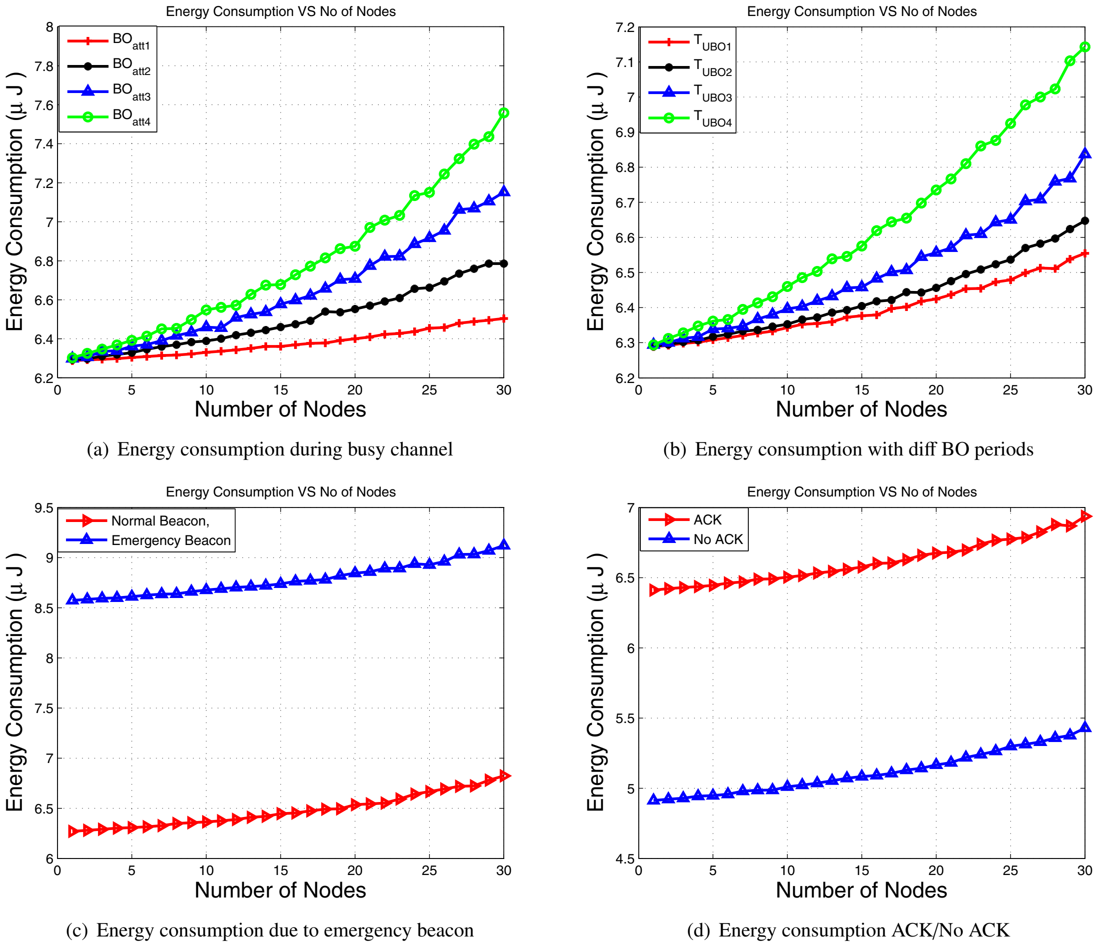
$$E_{tran} = P_{tran} \times T_{data}. \tag{6}$$

$$E_{total} = P_i(\lambda p - (T_{setup} + T_{beacon} + T_{cca} + T_{data} + T_{ACK} + T_b\tau) + (P_{rec} \times T_b\tau) + (P_{rec} \times T_{setup} + 2T_c + 2T_p) + P_{tran} \times T_{data})/\lambda p. \tag{7}$$

$$E_{extra} = P_i(\lambda p - (T_{setup} + T_{beacon} + T_{cca} + T_{data} + T_{ACK} + T_b\tau) + (P_{rec} \times T_{EXb}\tau) + (P_{rec} \times T_{setup} + 2T_c + 2T_p) + P_{tran} \times T_{data})/\lambda p. \tag{8}$$

Where, P_i, P_{rec}, and P_{tran} are power consumed in idle, receiving and transmission states. T_{setup} is setup time from idle state to transmission or listening state. T_{beacon} is beacon transmission time while, T_{cca}, and T_{data} are CCA and data transmission times. Average beacon inter-arrival time is denoted by T_b which defines the times between two beacons. T_c and T_p are control packet transmission and propagation time of the packet. λp denotes the packet inter-arrival time. At the end, τ is the busy channel probability.

In case of an emergency, AP transmits the short beacon to receive the time critical data. This will not affect the normal and periodic data transmission. This is because, BN uses the inactive period for data transmission. After emergency beacon, node transmit the data according to TDMA mechanism. However, if more than one node have an emergency data, AP broadcast the beacon to all the nodes. Then emergency period is divided into TDMA time slots to receive data from all the BNs. Here we can also modify the CAP, CFP, and IP duration in case of more emergency nodes. Increase the IP to facilitate more nodes during emergency data transmission.
Another main reason for energy consumption is packet inter-arrival time. If the inter-arrival time is more than service time, nodes will have to wait due to limited queue size. To avoid packet drops and energy consumption, there is great



(a) Energy consumption during busy channel

(b) Energy consumption with diff BO periods

(c) Energy consumption due to emergency beacon

(d) Energy consumption ACK/No ACK

Fig. 4: Energy consumption of IEEE 802.15.4 MAC protocol for WBAN.

need to adjust the packet inter-arrival time based upon the data rate and payload. For stability, service time should be less than packet inter-arrival time otherwise queue will overflow. Energy consumptions with different packet inter-arrival times and backoff periods are shown in figure. 4.

6. Conclusion

In this paper, we present the energy consumption analysis for MAC protocol which handles the three types of traffic. CSMA/CA mechanism is used for normal traffic while periodic traffic is transmitted through TDMA based time slots. AP transmits extra beacon for emergency data. However, all other data transmission is going without any interruption. Nodes transmitting data during emergency phase consume more energy while providing the reliability which is one of the main tasks for the development of WBANs. The simulation results show the energy consumption of BNs during different phases of the protocol. In future, we are interested to implement the aforementioned energy consumption behaviour of the BNs under specific application constraints.

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Table 2: Simulation Parameters .

Parameters	Values	Units
Data rate	250	Kbps (2.4 GHz)
Beacon Interval (BI)	15360	Symbols
Superframe Duration (SD)	7680	Symbols
Backoff period	20	Symbols
Inactive period	7680	Symbols
Clear Channel Assessment (CCA)	8	Symbols
Sensing time	$8 \times 16e^{-6}$	micro seconds
MAC acknowledgment wait duration	$120 \times 16e^{-6}$	micro seconds
Turnaround time	$400e^{-6}$	micro seconds
Wakeup time	$800e^{-6}$	micro seconds
A unit backoff period	$20 \times 16e^{-6}$	micro seconds
DIFS	$40 \times 16e^{-6}$	micro seconds
SIFS	$12 \times 16e^{-6}$	micro seconds
Time of Beacon Interval (BI)	$240 \times 10e^{-3}$	milli seconds
Time of Superframe Duration (SD)	$120 \times 10e^{-3}$	milli seconds
Interarrival time	0-2	seconds
Inactive time	$120 \times 10e^{-3}$	milli seconds
Transmission voltage	1.5	volts
Receiving voltage	0.9	vols
Receiving power	1.8	milli watt
Transmission power	31.5	milli watt
Inactive time	$120 \times 10e^{-3}$	milli seconds
Total load	70	Bytes
Acknowledgment (ACK) packet size	6	Bytes
MAC minimum backoff exponent	3	
MAC maximum backoff exponent	5	
MAC maximum frame retries	4	
Size of CW	8	
Number of nodes	0-30	
Beacon Order (BO) and Superframe Order (SO)	4 and 3	

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